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IMPACT OF IN-CHANNEL ORGANIC DEBRIS ON FLUVIAL PROCESS AND CHANNEL FORM

QUARTERLY REPORT TO THE US ARMY CORPS OF ENGINEERS

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Administrative Developments

Mr Wallerstein is now working in conjunction with Dr Frank Neilson at the hydraulics division of WES to asses the impact of debris at dams, weirs and navigation structures, as well debris jams in the DEC watersheds.

Logistics and Travel

Mr Wallerstein carried out fieldwork in Mississippi between 28th December and 16th January 1995. Working with the Colorado State University field survey crew he has re-surveyed sites in the DEC watersheds for which a data-set was gathered during May/June 1994. He is now making arrangements for the summer 1995 field visit.

Research Progress

A literature review has now been complied and written up and is enclosed as part of this document.

The second field data set will begin to shed light on the temporal dynamics of woody debris and will show the stability of debris jams at different channel scales, and the input/output rate of debris from the survey reaches. Because thalweg are not surveyed during the winter trip, bed level adjustments associated with debris jams cannot be assessed. However, the forth-coming summer survey will provide a new set of thalweg

data which can be overlayed on the summer 1994 thelweg plots to determine relative rates of bed elevation change.

Data Analysis

Survey data is now being processed and compared with the summer 1994 data set. The following conclusions have been made from analysis of the June 1994 data:

1) Literature review

The geomorphologic impact of woody debris has been extensively studied and documented, however, there remains few in any geomorphologic studies in unstable, degrading channel environments. A limited number of studied on the hydraulic effect of LWD have been carried out. A practical method for calculating the Darcy-Weisbach "f" and also the afflux associated with debris accumulations is presented in this report along with a method for calculating pier scour with floating debris accumulations.

2) Survey Results

A number of conclusions can be drawn from the initial field survey and data analysis.

Firstly, given the entrenched nature of many of the creeks being surveyed, and the permeability of the jams observed, it is unlikely that even the most complete debris dams will cause a serious increase in the level or duration of the over- bank flood potential. Very large, coherent, debris accumulations may occur however at man-made structures, such as against bridge piers, and without periodic clearance these will eventually cause a greater local flood risk.

It is worth considering the fact that large, coherent debris accumulations, such as that show in plate 3, will significantly affect channel hydraulics, through backwater effects, so obstructions such as this must be considered when mathematical flow routing models such as HEC 2 are used to calculate channel capacity and energy

gradients. Large debris jams could be incorporated as either very high local roughness values or as geometric elements in the channel profile.

From field observations it is apparent that the main LWD input mechanism in these channels is tree topple due to bank failure. Also in November 1993, over the period of one or two days, a heavy frost caused branches to tear off a large number of trees in the northern half on the DEC survey area causing a sudden influx of new debris material into many catchments. It appears, however that, much of this load, because it is composed of only limbs, rather than whole trees, has been moved by high flows to already established debris jam, rather than forming new sites of obstruction.

On a catchment-wide scale it is becoming apparent that major debris input regions and jam concentrations and to be found in laterally unstable reaches, especially downstream of knickpoints and knickzones. There is also some evidence indicating that regions of actively meandering channel are likely to contribute to major debris input and subsequently become choked by jams. No distinct, predictable, spatial pattern of debris jams is evident at the reach scale however.

As yet little information is available concerning the age and stability of particular debris jams, a crucial factor which must be considered for any effective management strategy. A rough estimation of the relative age of in channel trees and limbs can be made though observing the state of decay of the debris in question, but this does not necessarily mean that the debris has always resided at that particular location in the channel network since its input. Such time-trends will become apparent however as future data from the bi-annual re-surveys is collected.

Current thalweg profile plots provide little conclusive evidence about the magnitude of debris-jam related scour or sediment retention, but once again, future surveys of each reach will show exactly where and to what extent erosion and/or sedimentation is prevalent in debris filled reaches as compared to those which are debris-free. It is evident from the thalweg plots however that debris filled reaches have far more irregular bed topographies than those which are completely debris-free. It likely that the former will offer a more diverse habitat composed of pools and shallows,

as well as an abundant organic food and nutrient supply from the decomposing woody material, for aquatic flora and fauna, than the latter (Bilby & Likens, 1980).

3) Debris at Structures

Substantial woody debris accumulations were noted at a number of bridges, grade control structures and bendflow weirs during the survey period. Plate 5 shows a debris accumulation against the piers of a country road bridge over Hickahala Creek (11), Site 1. There does not appear to be any significant basal scouring associated with this jam, but the increased pressure force, during high flows, due to debris loading at each piers may compromise the structural integrity of this bridge. Plate 6 shows a debris accumulation against the baffle of a grade control structure on Hickahala Creek (11). This accumulation is as yet not large enough to cause a significant reduction in capacity in the stilling basin, or cause a backwater effect above the weir jump level. Plate 7 shows two bendflow weirs on Harland Creek (23) which are designed to induce bank-base sedimentation on the outside of eroding bends. Woody debris has been brought to rest on, or between, many of these weirs and incorporated into the accumulating sediment wedge. Larger debris, however, also appears to cause the displacement of riprap from these structures during high flow.

<u>Plans For The Next Quarter</u>

* Analysis of the January 1995 data-set and comparison with the June 1994 set.
* Arrangement of month-long field visit with the DEC survey crew in May/June 1995
* Submission of end of contract report to US Army corps of Engineers
* Preliminary investigation of a UK field study site.

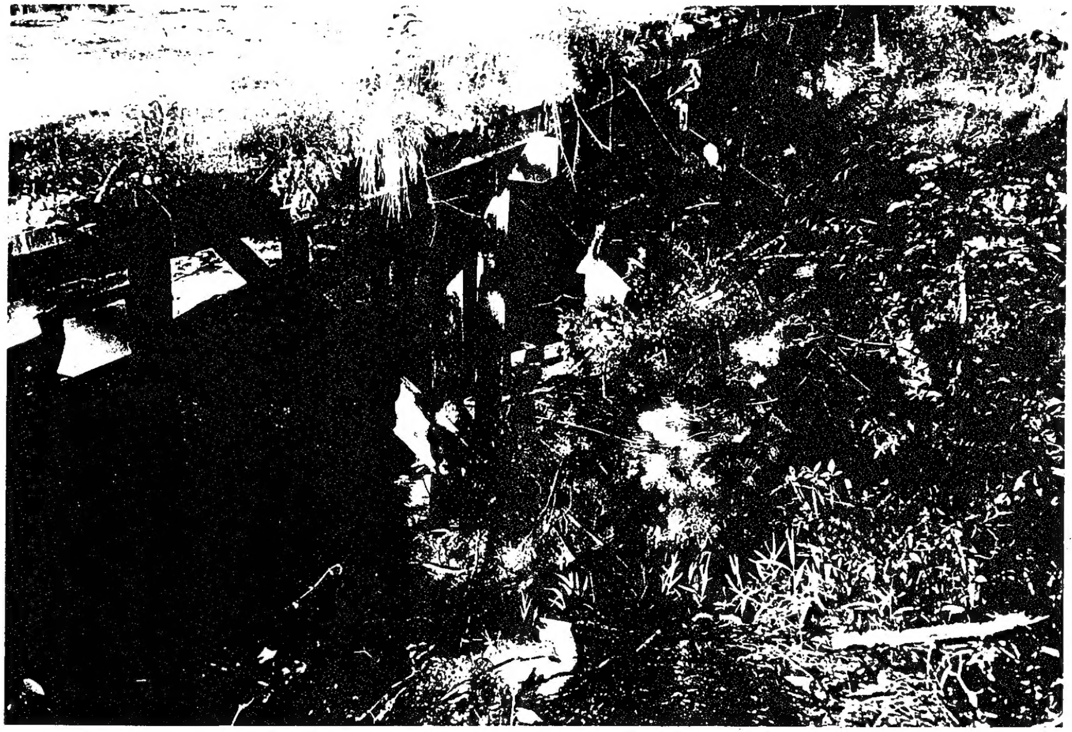


Plate 5 : Debris accumulation against bridge piers. Hickahala Creek (11), Site 1

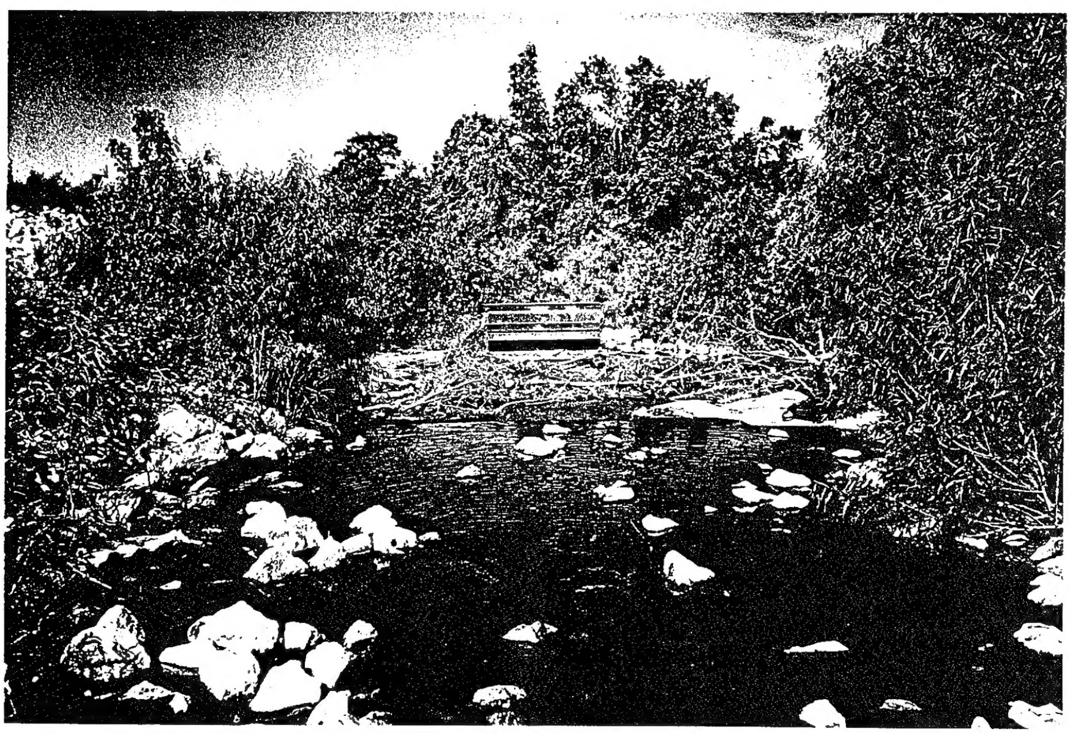


Plate 6 : Debris accumulation against baffle at grade control structure. Hickahala Creek

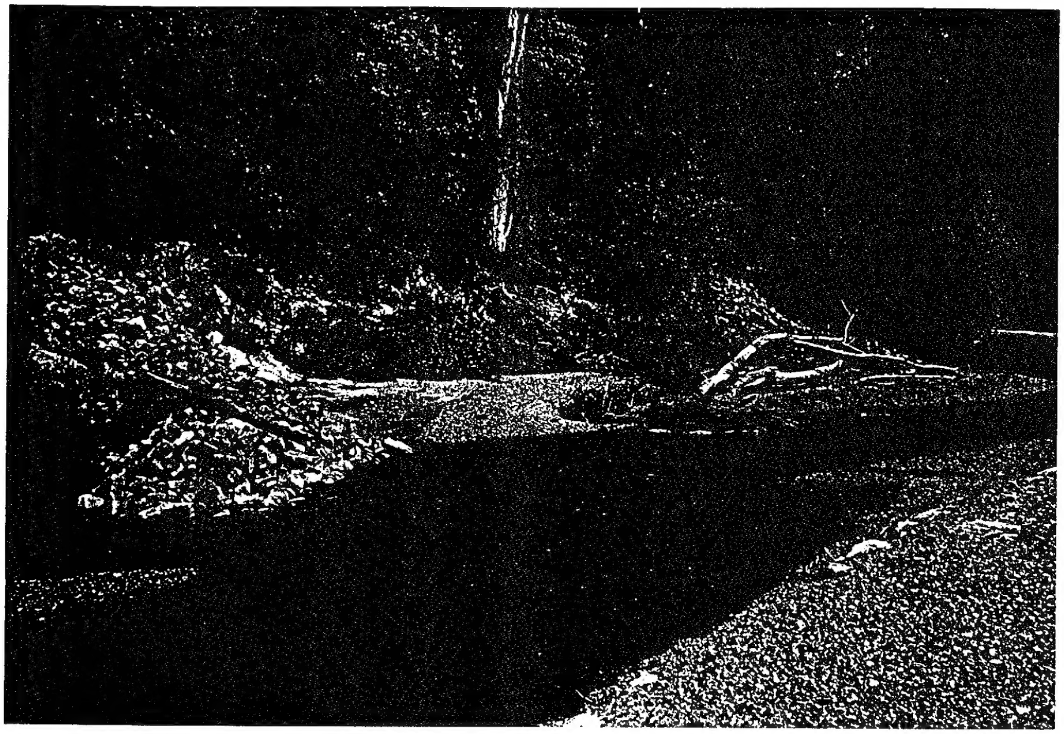


Plate 7 : Whole tree and smaller timbers on bendflow weirs. Harland Creek (23)

1 LITERATURE REVIEW

1.1INTRODUCTION

In a literature review of published material then available, Hickin (1984) suggested that vegetation may influence channel processes through five mechanisms:

a) Flow resistance

b) Bank strength

c) Bar sedimentation

d) Formation of log jams

e) Concave-bank bench deposits

He also stated that the literature concerning this subject was of two main types: that dealing with the indirect influence relations between vegetation, water, sediment yields and river morphology; and that dealing with the direct impact of channel vegetation on channel morphology. The latter was, in 1984, limited to only a few papers.

There has been a rapid increase in recent years, however, in the number of studies concerning coarse woody debris (CWD) or Large Organic Debris (LOD) (Hogan, 1987) and its accumulation as jams or dams in river channels. This is probably a result of the current shift from hard to soft engineering practices and adoption of a more holistic approach to river basin and channel management.

Studies can be grouped by topic into those dealing primarily with : .

a) Input process

b) In-channel effects

c) Fluvial transport processes.

Each of these processes varies depending upon stream size relative to CWD size (Nakamura et al, 1993).

Most studies have been carried out in essentially stable channel environments in the U.S. and Canadian Pacific Northwest, in the U.K., and in New Zealand. Instability in the form of landsliding, is cited by Pearce & Watson (1981) as a means for debris to enter channels, but the impact of debris on inherently unstable channels has not been assessed.

1.2 QUANTITY AND DISTRIBUTION OF LWD

1.2.1 Input Processes

Large Organic Debris enters river systems by two main processes; either from outside the channel due to bank erosion, mass wasting, windthrow, collapse of trees due to ice loading or biological factors (death and litter fall (Keller, 1979)); or from inside the channel, through erosion and flotation of material (Hogan, 1987), (Figure 1.1). Once in a channel, debris may form into jams or dams.

In this paper the term "jam" is used for a partial blockage and "dam" refers more specifically to the complete blocking of flow along a channel.

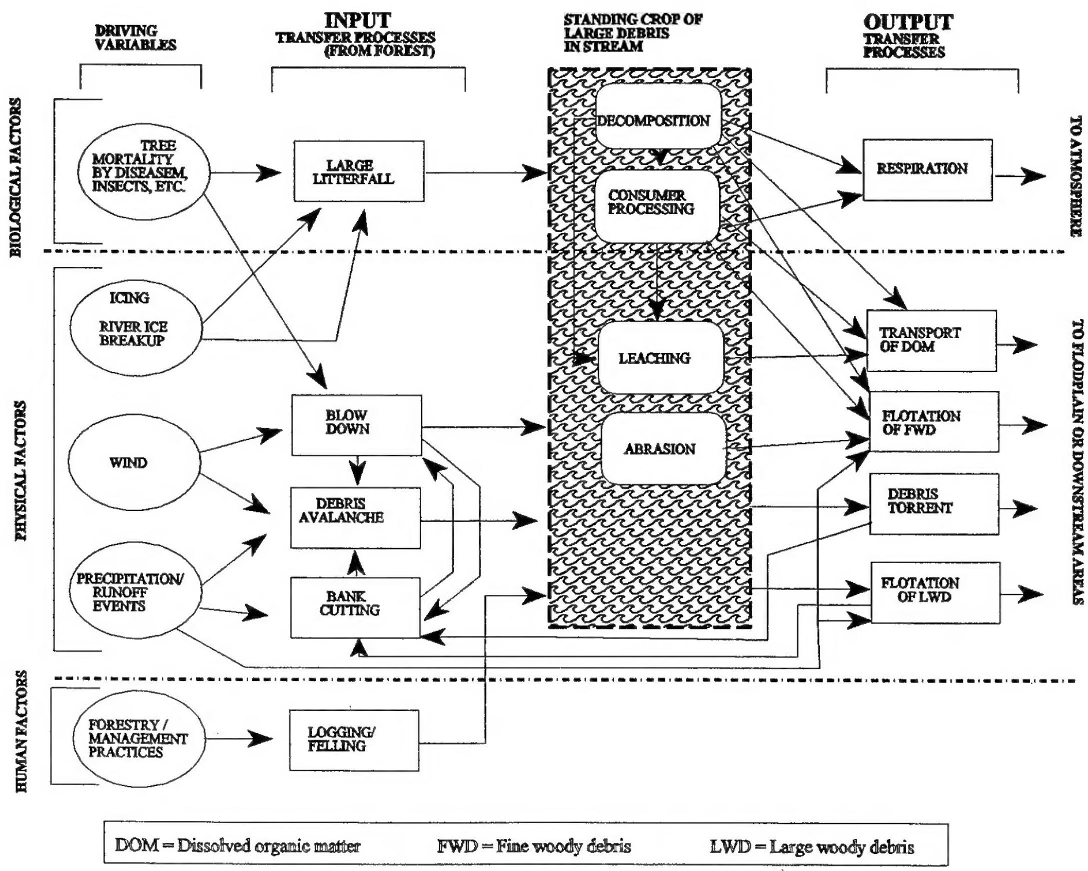
1.2.2 Formation of Jams

Jams often form around "key coarse woody debris" (Nakamura, 1993), which are usually large, whole trees that have entered the channel by one of the mechanisms mentioned above and which are anchored to the bed or banks at one or both ends. Smaller debris floating down the channel then accumulates against this feature, which acts as a sieve to debris and, later to sediment. If there is no fine debris present a jam may never form, so that the impact of key-debris is minimal.

1.2.3 Residence time of debris jams

The residence time, or permanence, of debris jams is an important factor, which determines the extent to which channel morphology will be adjusted. Assessing residence time is difficult and estimates range between 12 months, for a 36% change or removal (Gregory & Gurnell (1985), to 40-90 years (Hogan, 1987), to 200 years in streams in British Columbia (Keller

DYNAMICS OF WOODY DEBRIS Figure 1.1



(adapted from Keller & Swanson, 1979)

& Tally, 1979). This factor largely depends upon the occurance of long return period floods and is ,therefore, river specific.

1.3 IN-CHANNEL GEOMORPHIC SIGNIFICANCE

1.3.1 Effects of channel scale

It is important to recognise that processes are scale dependant. For example, Zimmerman et al. (1967) found that debris accumulations in a very small stream completely obscured the usual hydraulic geometry relations, while Robinson & Beschta (1990), and Keller & Tally (1979) suggest that debris loadings increase with stream size. Gregory et al. (1985), have characterised jams into three types :

1) Active (form a complete barrier to water and sediment movement, and create a distinct step or fall in the channel profile)

2) Complete (a complete barrier to water/sediment movement but no step formed)

3) Partial (only a partial barrier to flow)

They suggest that these types become sequentially more prevalent as channel size increases. In this study, the Gregory et al. classification was incorporated into the field analysis, as it was evident that jam size and orientation were extremely important in terms of channel process control. Similarly, Robinson & Beschta's (1990), Deflector, Underflow, and Dam flow direction criteria and debris zonation criteria were used in the field studies (see Appendix D).

In small streams debris will accumulate where it falls because the flow is not competent to move material, but in larger streams distinct jams may form, while in even large rivers debris may never accumulate because it is carried away downstream.

Once trees fall into a stream, their influence on channel form and process may be quite different to that when they were on the banks, changing from stabilizers to destabilizers through local scour and basal erosion. Thus, jams represent a type of auto-diversion: that is, a change in

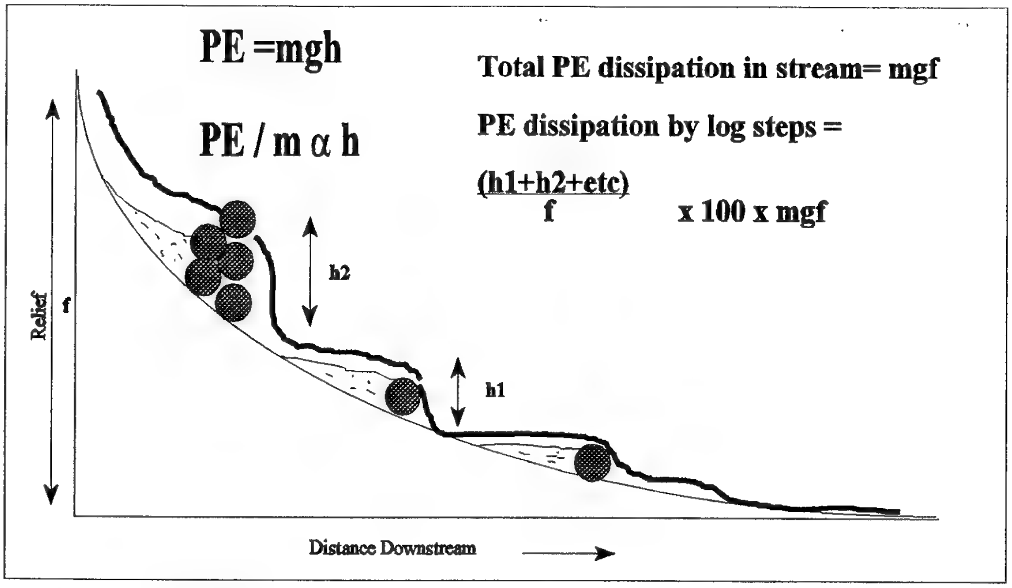
channel morphology triggered by the fluvial process itself. The impact on morphology is dependent primarily on the channel width/tree height ratio and on debris orientation relative to the flow. Mean discharge and the dominant discharge recurrence interval are also important because the higher the flow is relative to jam size, the smaller will be the jam's impact in terms of acting as a flow diverter and roughness element.The principle effects of debris upon channel morphology are described below.

1.3.2 Impact of debris jams upon channel morphology

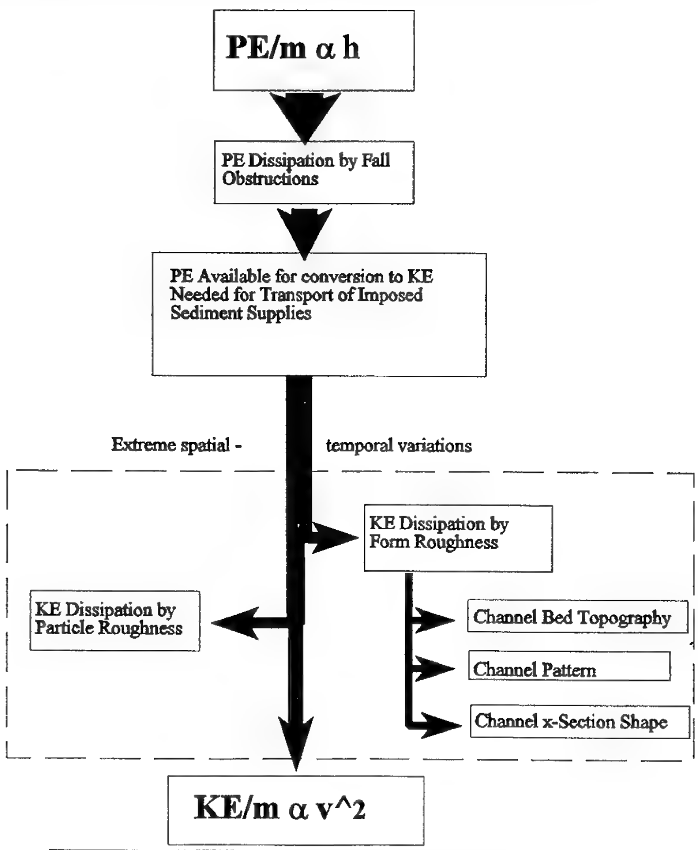
Mosley (1981) found at Powerline Creek, New Zealand, that along 40% of the channel stream bed contours, the location of riffles, pools and gravel bars were related to flow patterns induced by organic debris. Studies in the Pacific Northwest have also shown that a considerable proportion of the vertical fall of channels can occur at the sites of debris jams, accounting for 60% of the total drop in some streams such as Little Lost Man Creek in Northern California (Keller & Tally, 1979). Debris jams therefore act as local base levels and sediment storage zones which provide a buffer to the sediment routing system. On this basis, Klein et al. (1987) argue that jam removal can cause upstream base level change and bank erosion. Random debris input will also distort the riffle-pool sequence making it less systematic, so that the channel in long profile has very little spatial memory, or periodicity (Robinson & Beschta, 1990).

Potential energy is dissipated at jams, with energy loss being as much as 6% of total potential energy (MacDonald et al., 1982). Stream power distribution is altered and further effects arise through the influence of jams on the location of erosional and depositional processes and through the backwater affect created by jam back-pools (Keller et al. 1976). Thus, in small, stable channels, log steps generally increase bank stability and reduce sediment transport rates by creating falls, runs and hydraulic jumps. Figure 1.2 shows how potential energy is lost through a log-step sequence. This localised dissipation of energy can, however, result in associated local scour and bank erosion which causes channel widening, although Keller & Tally (1979) also

Energy Transformations in Streams with Log Steps — Figure 1.2



Potential stream energy per unit mass of water (PE/m) is directly proportional to h, or the relief in a specific stream.
PE dissipation by log steps = Cumulative change of water surface elevation (h1+h2+ etc) as a percentage of total stream relief (f)



Log steps cause a reduction in potential energy that would otherwise be converted to a longitudinal component of kinetic energy actually used for sediment transport (PE/m = potential stream energy per unit mass of water; KE/m = kinetic energy per unit mass of water; h = relief in a specific segment; v = stream velocity

(adapted from Marston, 1982)

observed channel narrowing, caused by flow convergence underneath logs, with sediment storage upstream and a scour-pool downstream.

As the channel width/tree size ratio becomes greater than unity flow is diverted laterally, inducing bank erosion and local pool scour. Hogan (1987) found that in undisturbed channels in British Columbia organic debris diagonally crossing the channel resulted in high width and depth variability, whereas in catchments where there had been logging operations, the majority of in-channel discarded timber was parallel to the flow, and subsequently became incorporated into the stream banks, protecting them from erosion. Nakamura & Swanson (1993) have suggested that there is a progression of debris/channel interactions, ranging from base level control and possible local widening in low-order streams, to lateral channel shifts and increased sinuosity in middle-order channels, to bar formation and flow bifurcation in high-order streams. This last process has been documented by Nanson (1981), again in British Columbia, who found that organic debris deposited at low flow provided the nuclei for development of scroll bars, through the local reduction of stream power. Hickin (1984) also observed crib-like bar-head features, but was undecided as to whether the debris caused bar formation, or whether the bars pre-dated and trapped the debris. In either case organic debris would, at the very least, enhance sediment deposition and bar formation.

1.4 HYDRAULIC SIGNIFICANCE OF LWD

A comprehensive investigation of the hydraulic effect of LWD in rivers has not been documented. However some studies have investigated the effect of LWD on channel roughness, the hydrograph, velocity distribution and water surface profile

1.4.1 **Effect of LWD on channel roughness**

The Manning's "n" equation generates a roughness coefficient from all sources in the channel. This flow equation is widely used by river engineers who select values of "n" from tables in Chow (1959) or from photographs in Barnes (1967). The range of n coefficient in normal channels is from 0.025 to 0.15. For heavily congested streams less than 30m wide n ranges from 0.075 to 0.15. Irregular and rough reaches of large streams have values of n from 0.035 to 0.10.

$$n = \frac{R^{2/3} S^{1/2}}{V} \qquad \text{or} \qquad n = \frac{1.49}{V} R^{2/3} S^{1/2} \tag{1.1}$$

R = hydraulic radius (m), S = energy slope, V = mean velocity (ms^{-1}), 1.49 = conversion to fps units.

The hydraulic effect of LWD varies as a function of relative depth of flow. Bevan et al. (1979) found that when LWD is high in relation to flow depth the roughness coefficient is extremely high (Manning's n>1). As LWD becomes structurally submerged it exerts less influence on flow hydraulics. Shields and Smith (1992) measured a large decrease in Darcy Weisbach friction factor as discharge increased, and also observed that friction factor, for cleared and uncleared reaches, converged at high flows. Indirect evidence for these findings is provided by investigations of downstream hydraulic geometry which shows that roughness generally decreases as channel size increases (Wolman, 1955). Petryk and Bosmajian (1975) derived an equation to predict Manning's

n as a function of density of vegetation in the channel, hydraulic radius, Manning's n due to boundary roughness and a vegetation drag coefficient.

$$n = n_b \sqrt{1 + \frac{Cd \sum Ai}{2gAl}\left(\frac{1.49}{n_b}\right)^2 \left(\frac{A}{P}\right)^{2/3}} \tag{1.2}$$

n_b = Manning's boundary roughness coefficient excluding the effect of vegetation; Cd = drag coefficient for vegetation (assumed to be 1); Ai = projected area of the ith plant in the streamwise direction; A = cross-sectional area of flow; L = length of the channel reach being considered; P = wetted perimeter of channel.

In this formula the expression CdΣAi/AL represents the density of vegetation in the channel.

Gippel et. al. (1992) note that a problem with this formula is selecting a value for the drag coefficient Cd. Petryk and Bosmajian assumed a value of 1 but this applies to cylinders in infinite flow. In streams, interference from nearby obstructions and the effect of blockage on the drag coefficient need to be considered.

The Manning equation is however, inappropriate in situations where there is a high degree of obstruction in the channel, particularly where n >1. The Manning equation was developed empirically to describe open channel situations with fully turbulent flow where friction is controlled by drag from the channels surface. The equation attaches significance to the hydraulic radius which may be irrelevant if the channel is heavily choked with LWD.

Smith and Shields (1992) studied the effects of varying levels of LWD density on the physical aquatic habitat of South Fork Obion River, Tennessee, USA. Two secondary objectives in this study were to develop and demonstrate a method for quantifying LWD in a given reach and to relate the quantity of LWD to reach hydraulics. An approach similar to that used by Petryk and Bosmajian (1975) was used to calculate the effect of LWD on channel roughness. The LWD density in a reach was calculated using the following formula :

$$DA = \sum_{i=1}^{n} \frac{A_i}{A} L_r = (1/L_r) \sum_{j=A}^{D} F_{bj} \sum_{k=1}^{3} N_{j,k} F_{wk} \tag{1.3}$$

where

n = total number of LWD formations in the reach

A_i = area of the ith debris formation in the plane perpendicular to flow

A = reach mean flow cross-sectional area

L_r = reach length

F_{bj} = formation type weighting factor for jth formation type.

$N_{j,k}$ = number of type j LWD formations in Kth width category.

F_{wk} = weighting factor based on LWD formation width category.

See Appendix B for a description of the weighting factors.

Rather than Using Manning's n, the more theoretically based Darcy-Weisbach flow resistance equation was used, which can be expressed as:

$$f = \frac{8gRS_w}{V^2} \tag{1.4}$$

where

f = Darcy-Weisbach friction factor; R = hydraulic radius; S_w = water surface slope

In a channel reach where LWD plays a major role in flow resistance, total resistance can be expressed as:

$$f_t = f_b + f_d \tag{1.5}$$

where

f_t = total Darcy-Weisbach friction factor

f_b = boundary friction factor excluding LWD effects

f_d = friction factor due to LWD

Total head loss is the sum of a boundary friction loss and a LWD blockage loss, as follows:

$$h_L = S_E L = \frac{\left[(f_b L / 4R) + K_d\right]V^2}{2g} \tag{1.6}$$

where

h_L= total head loss

S_E = slope of the energy gradient

K_d = dimensionless loss coefficient (dependent upon LWD density)

The energy slope can be calculated using a total friction factor from the Darcy-Weisbach equation:

$$S_E = \frac{f_t V^2}{(8gR)} \tag{1.7}$$

Substituting this expression for S_E into equation 6 gives:

$$f_t = f_b + \frac{4RK_d}{L} \tag{1.8}$$

Therefore:

$$f_d = \frac{4RK_d}{L} \tag{1.9}$$

The ratio K_d/L may be expressed in terms of the LWD density as:

$$K_d / L = DA \tag{1.10}$$

Smith and Shields calculated values for f_b using curves developed by Alam and Kennedy (1969) and hydraulic parameters determined from dye tracer tests in the LWD reaches, which provide direct discharge and velocity estimates (Richards 1982), and the median bed grain size determined from sieve analysis. Values for f_d were then calculated using equations 1.3, 1.9 and 1.10. They then compared computed values of f_t with values measured using dye tests.

The results of their study showed a reasonable positive correlation between the measured and computed friction factors. However, they recognise that considerable refinement and site-

specific adaptation may be in order, and that the method does not account for local energy loss because of bends or flow expansion and contraction at bridges, debris dams, or riffles. The method does have a sound theoretical basis however and could be usefully employed in future research into LWD hydraulics.

1.4.2 Effect of LWD on velocity distribution

LWD clearly influences the direction and magnitude of flows currents within stream flow, but few data have been documented in the literature. Swanson (1979) produced detailed maps of debris jams indicating flow with directional arrows. Smith and Shields (1990) reported that the removal of LWD from a river 18-23m wide 3.5 to 4.5 m deep produced more uniform flow, and less of the channel was occupied by eddies or regions of reduced velocity.

1.4.3 Effect of LWD on stage/discharge relationships, the hydrograph and flood frequency

LWD is often removed because it is assumed that this will achieve a significant reduction in channel roughness which will allow a higher mean flow velocity and thereby increase channel capacity. There is some evidence to support this assumption. For example Smith and Shields (1990) measured the mean flow velocity in two cleared reaches of a river to be 0.04 m/s and 0.34 m/s. In an uncleared reach of the same river the mean velocity was 0.27 m/s. MacDonald and Keller (1987) also found that there was a local increase in velocity by up to 250% as a result of LWD removal and a decreased sinuosity of the low flow thalweg. According to Gippel et al (1992) the Murray-Darling Basin Commission calculated a theoretical reduction in water level of 0.3 - 0.4 m after the removal of approximately 200 snags per kilometre. However, later analysis of flow records indicated a reduction of only 0.2 m. In theory there should be a statistical reduction in the magnitude and frequency of overbank flooding where debris is removed from a channel because of the increased channel capacity. Bodron (1994), used a dynamic routing model to demonstrate

changes in both stage and duration of flood events before and after LWD removal, using Manning n values calculated in the study by Smith and Shields at South Fork Obion River, west Tennessee. Despite the increase in channel cross-sectional area due to LWD removal being ignored, small reductions in flood height and duration were calculated based solely on the change in Manning's n values. Bodron also notes that flood stage would be reduced further if sediment accumulations at each jam site had been removed. However, according to Gippel et al (1992) many claims that this effect has been achieved lack any supportive evidence. Counterclaims also lack supportive evidence, because of the difficulty of isolating the hydraulic effect of LWD removal. It is even possible that LWD removal might increase flood peaks, because the downstream flood wave is not attenuated so much.

Gregory et. al. (1985) found that LWD ponds water which results in an increase in water depth and a decrease in velocity, which, at low flows influences travel time significantly. At high flows, however, the ponding effect of LWD is drowned out.

Shields and Nunnally (1984) noted that because large accumulations of LWD have a damming effect on the flow which locally elevates the base level they can be treated as geometric elements within the channel rather than simply as roughness elements, in backwater profile computations.

1.4.4 Modelling the hydraulic effect of LWD

Most studies of resistance to flow in rivers have concentrated on small-scale roughness, especially skin friction offered by bed sediments, where the size of the roughness element is small compared to the flow depth. LWD on the other hand represents large-scale roughness, for which skin friction is small compared with form drag (Petryk and Bosmajian, 1975). Flow conditions associated with the presence of LWD in streams varies from sub-critical to super-critical depending on the dimensions of the LWD and the depth of water.

Gippel et. al. (1992) used the momentum principle to determine the hydraulic effect of LWD, the effect being quantified in terms of afflux or backwater effect. If flow is subcritical (Froude number < 1), apart from local disturbance of the velocity profile, LWD only has an influence in the upstream direction. There are often practical difficulties with directly measuring the afflux at debris jams, however, an alternative to direct measurement is prediction on the basis of a known relationship between afflux and more easily measured parameters. Gippel et. al. used the results of a laboratory hydraulic study to develop a method of determining the afflux caused by LWD.

They propose the use of the following equation to calculate afflux :

$$\Delta h = \frac{h_3\left[\left(F^2 - 1\right) + \sqrt{\left(F^2 - 1\right)^2 + 3C_D BF^2}\,\right]}{3} \tag{1.11}$$

where

Δh = afflux = $h_1 - h_3$ (m)

and the drag coefficient :

$$C_D = \frac{F_D}{\frac{1}{2}\,\rho U_1^2 L_* d} \tag{1.12}$$

F_D = drag force (N)

ρ = density of water (approx. 1000 kg/m^3)

U_1 = mean velocity at section upstream of object (m/s)

L_* = projected length of LWD in flow (m)

d = diameter of LWD (m)

and the Froude number:

$$F = \frac{U_3}{\sqrt{gh_3}} \tag{1.13}$$

U_3 = mean velocity at section downstream of object (m/s)

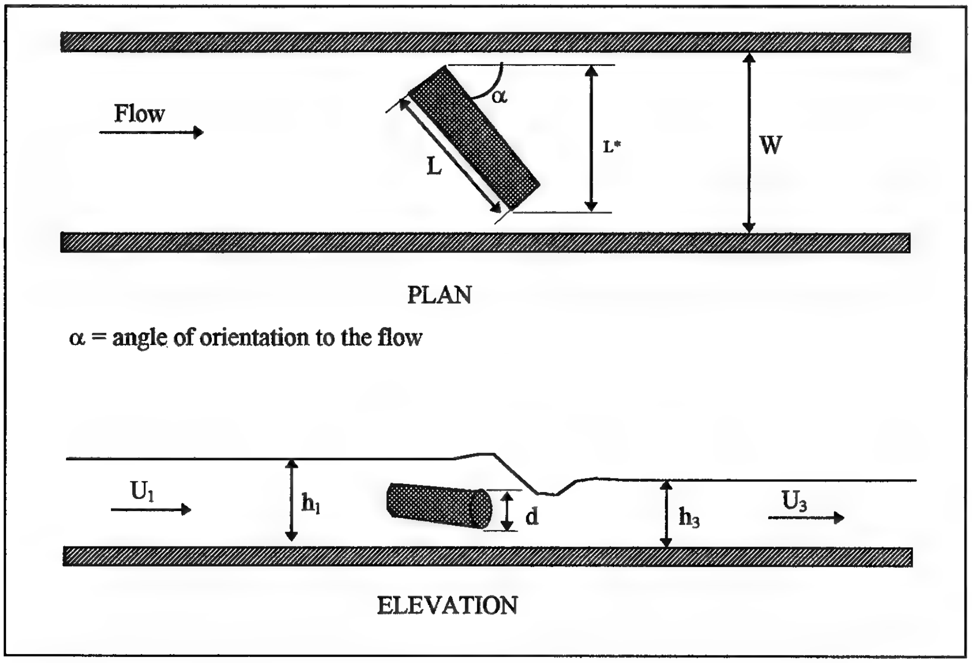
h_3 = water depth downstream of LWD (m)

and the blockage ratio:

$$B = L_* d / A \tag{1.14}$$

$A = W.h_1$ = cross sectional area of flow (m^2)

Figure 1.3 Definition sketch of LWD model used in flume by Gippel et. al. (1992)



Thus the afflux depends on F, C_D and B. The Froude number can be calculated from direct measurement or from flow records. B can be found from survey. The problem comes in selecting an appropriate drag coefficient. The drag characteristics of a cylinder in infinite flow are well known (Petryk and Bosmajian, 1975). Less is known about drag on cylinders within boundaries (the "blockage effect") where the drag coefficient is increased. Gippel et. al. conducted experiments on LWD models to determine drag force, using a towing carriage and water tunnel. Froude number, LWD length to diameter ratio and LWD depth from the bed all affected drag coefficient, but were much less important than the blockage effect, angle of orientation to the flow and the shielding effect (of one piece of LWD behind another). A suitable drag coefficient (C'_D) for

the LWD in question can therefore be selected from their experimental results (Gippel et. al. 1992, figures 3.8 or 3.12) on the basis of its overall shape and angle of orientation. See Appendix C. The drag coefficient should then be adjusted for the blockage effect, which can be calculated using the following equation developed by Gippel et. al. using their empirical data from flume studies :

$$C_D = C'_D\,(1\text{-}B)^{-3} \qquad (1.15)$$

where

C'_D = drag coefficient in infinite flow.

These data are then substituted into equation 1.11 to calculate the afflux.

Predicted and measured afflux values resulting from the flume study were very closely correlated, and they conclude that the flume conditions did not seriously violate any of the assumptions in equation 1.11.

The proposed method of afflux estimation was then applied to data collected from the Thomson River, Victoria, and revealed that de-snagging there would produce a reduction in stage of only 0.01m at bankfull flow.

In conclusion then, this method of backwater, or afflux calculation due to individual items of LWD could be used as a tool to help determine whether the afflux reduction due to LWD removal would have a positive impact according to the perceived management requirements or whether it could be left in place perhaps, re-orientated, lopped or even re-introduced where sympathetic rehabilitation management is desirable.

Appendix C contains a summary of the method developed by Gippel et. al. (1992) for predicting the afflux generated by LWD.

Young (1991) carried out a series of experiments in a flume using scaled LWD pieces in order to determine the order of magnitude of the increase in flood levels caused by LWD at different positions within the channel cross-section. Results indicated that the frontal area of LWD , as a percentage of the channel cross-section, had to be very high in order to cause a significant rise

in stage (a 10% stage rise required a frontal area of 0.8 x the channel cross-section). LWD position variables were also examined. For example, it was found that LWD near the bed will cause a greater hydraulic effect than LWD higher in the cross-section, and that a 50% reduction in the stage rise (from that due to LWD aligned perpendicular to the channel) requires a 40 degree rotation of the LWD from the perpendicular. Young concludes that his results indicate that the amounts of LWD which are found in lowland rivers, in Australia, will seldom have a significant effect on flood levels, except where large log-jams form. However, he also notes that where rivers are used to supply irrigation water tolerances in water level are often lower and hence LWD removal may be necessary more frequently.

Cherry and Beschta (1986) conducted a series of tests using a 6 metre trapezoidal flume, with sand bed and wooden dowel LWD pieces to evalute the effect of debris on local channel morphology in terms of depth and area of associated scouring. Maximun scour depths were significantly correlated with both the vertical orientation of the dowel (Beta angle) and the channel opening ratio (ratio of projected dowel length to channel width). Scour surface area were significantly correlated with both flow depth and vertical orientation. Results indicated that scour depths were maximum when LWD was flat on the bed, and then declined as the Beta angle increased. Scour depths were also at a maximum when the horizontal angle (alpha angle) of the debris to the channel was 90 degrees (perpendicular to the flow), with the second greatest depths occuring when the debris was angled up-stream at 150 degrees. Similarly, as the Beta angle was increased so the area of scouring declined and the area of scour was at a maximun when the debris was orientated at 90 degrees to the channel. It was found that as flow depth increased, so the area of scour increased. Finally, it was observed that upstream-orientated dowels deflected flows towards the bank, while downstream orientated dowels deflected flow away from the bank and therefore appear to provide better protection from scour related failure.

1.5 IMPACT OF LWD AT BRIDGES

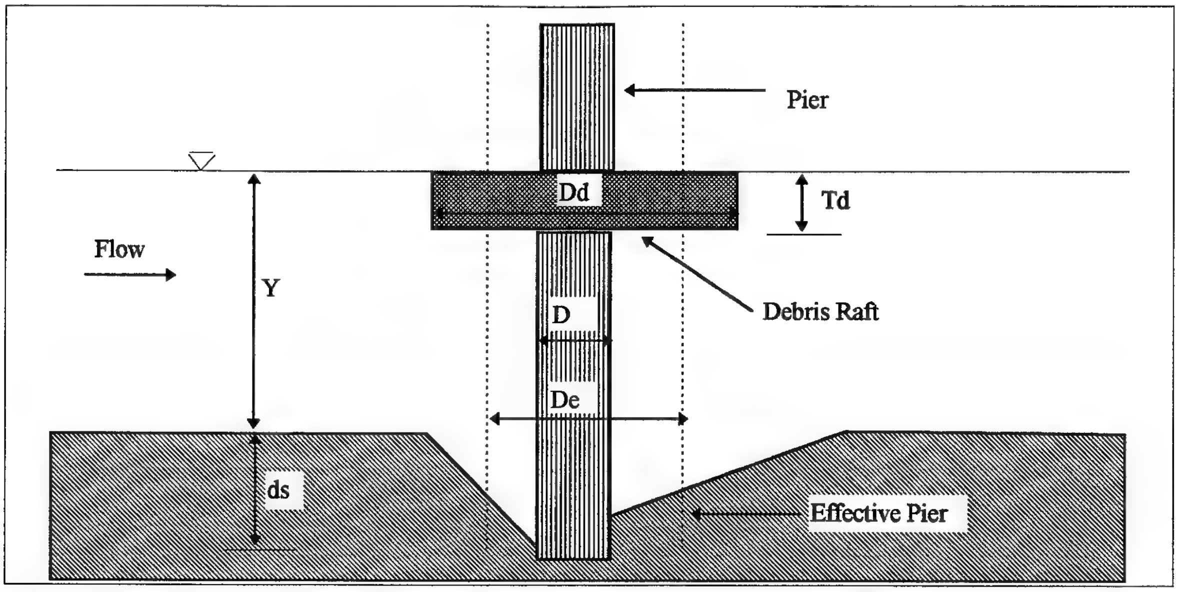
1.5.1 Theory

There are only a limited number of studies that have addressed the problem of debris accumulations at bridges. Melville & Dongol (1992) look at the problem of pier scour due to debris, while Simons & Li (1979) have used a probabilistic approach to quantify the rate of bridge span blockage by debris and the subsequent backwater effect and pressure forces generated on the piers.

Local scour at bridge piers has been extensively investigated. However the impact of debris rafts at piers which create additional flow obstruction and therefore increase scour depths has been largely neglected. A design method for estimation of scour depths at piers is presented by Melville and Sutherland (1988), based on envelope curves from laboratory data. The largest local scour depth at a cylindrical pier is estimated to be 2.4D where D is the pier diameter. 2.4D is reduced however using multiplying factors where clear-water scour conditions exist, the flow is relatively shallow, and the sediment size relatively coarse. In the case of non-cylindrical piers, additional multiplying factors to account for piers shape and alignment are applied. Consideration of the likelihood and extent of floating debris is not addressed by Melville and Dongol (1992) but is assessed by Simons and Li (1979). Melville and Dongol do note however that single cylindrical piers are the least likely to accumulate debris, and that the free space between columns is seldom great enough to pass debris. Prediction of the size of possible debris rafts remains the biggest problem.

The experimental arrangement used by Melville and Dongol is shown in Figure 1.4.

Figure 1.4 Experimental Setup



The design curve for pier scour without debris accumulations, developed by Melville and Sutherland (1988) is described by the following two equations:

$$\frac{ds}{D} = 1.872\left(\frac{Y}{D}\right)^{0.255} \qquad \left(\frac{Y}{D} < 2.6\right) \qquad (1.16a)$$

$$\frac{ds}{D} = 2.4 \qquad \left(\frac{Y}{D} \geq 2.6\right) \qquad (1.16b)$$

This shows that scour depth increases with increasing flow depth towards a limiting value for Y/D>2.6. The same trend is found for piers with debris accumulations for values of Y/D<4. At higher values of Y/D scour depths decrease again because the proportion of pier length covered by debris decreases. For deep flows the effect of debris would become insignificant and tend towards the value ds/D =2.4.

The effective diameter of a pier with a debris accumulation, De, is given by,

$$De = \frac{Td^{*}Dd + \left(Y - Td^{*}\right)D}{Y} \qquad (1.17)$$

According to (1.17) De is calculated as a weighted average of an effective length Td^{*} = 0.52Td of the debris raft with diameter Dd and a length of the pier (Y- Td^{*}) with

diameter D. See figure 1.4. (The factor 0.52 was determined by evaluating the limits of Td and Dd/D for the hypothetical case where D is assumed to be zero and the debris is assumed to extend to the base of the scour hole).

D can therefore be substituted for De to calculate scour depth at piers with debris accumulations using the Melville and Sutherland design method. Conversely a maximum allowable Td and Dd can be calculated by specifying an upper scour depth within an acceptable factor of safety for a given pier size.

The rate of debris accumulation at bridge is difficult to quantify. The only method found in the literature is that presented by Simons & Li (1979) in a Msc thesis by Callander entitled "Fluvial Processes occurring at bridge sites " (from CSU, 1980).

According to Simons & Li, the trapping efficiency of a bridge is determined by:

1) Clearance beneath the bridge

2) Span lengths

3) Size and concentration of debris elements

The following possible consequences are identified which can result from debris blockage:

1) Backwater effects

2) Potential local flow diversion

3) Channel avulsion

4) bridge failure

Simons & Li express the volume of debris as a fraction of the sediment yield, and state a vegetation debris yield of 1%. In an attempt to estimate the number and volume of trees arriving at a bridge they utilise the volume of flood-plain erosion necessary to yield a tree, and use a representative tree size for the watershed.

Trees are assumed to be cylindrical with a diameter Dt, and a height Ht. The span between piers is Ls and the clearance between the water surface and the underside of the bridge is C. The chance that a tree will be trapped depends on a larger diameter however, Db, which represents either the canopy dimension or the root zone, whichever is larger. See figure 1.5.

If Ht > Ls the probability of at least one average tree being trapped is 100%. The blocked area is then estimated to be, NHtDt, where N is the equivalent number of average trees assumed to be trapped against the upstream face of the bridge.

If Ht < Ls a probabilistic approach is used.

Pt is the probability of a tree being trapped, and as the blockage beneath a span increases so the chance of other trees being trapped increases. The probability of the first tree being trapped is assumed to be a ratio of half the tree diameter, Db, to the total waterway area beneath a span, LsC.

$$PT1 = \frac{\frac{1}{2}\left(\pi Db^2 / 4\right)}{LsC} = \frac{\pi}{8}\frac{Db^2}{LsC} \tag{1.18}$$

Li (1980) observed that a tree caught on a pier will in general lie with its trunk in the direction of flow. A tree thus trapped offers an area of

$$\frac{1}{2}\left(\pi Db^2 / 4\right) = \pi / 8 Db^2 \tag{1.19}$$

to trap other debris.

In general when (m-1) trees are trapped beneath a span the probability of an mth tree becoming trapped is

$$PTm = \frac{\pi Db^2 / 8}{LsC - (m-1)(\pi Db^2 / 8)} \tag{1.20}$$

The probability of passing all NT trees from the watershed is

$$(1\text{-PT1})^{NT} \tag{1.21}$$

The probability of at least one tree being trapped at a span is

$$P1 = 1-(1-PT1)^{N} \quad (1.22)$$

where N is the equivalent number of average trees arriving at the span. According to Li (1980) most trees will stay close to the bank, thus

$$N = NT / 2 \quad (1.23)$$

The probability that m trees will be trapped is

$$Pm = [1-(1-PTm)^{[N-(m-1)]}]P(m-1) \quad (1.24)$$

On this basis the probability of a least m trees being trapped (for any m < N) can be estimated. The value of m can correspond to a chosen design criteria, for example maximum values of Td and Dd in the Melville and Dongol method. In order to calculate Td and Dd there needs to be an estimate of the blockage area. It is assumed that debris elements stack up and that trees overlap by Dd/2. Thus for m trees trapped the percentage of the waterway area which is blocked is

$$\%Blockage = \frac{m(\frac{1}{2}\pi\, Db^2/4)}{LsC} \times 100\% \quad (1.25)$$

Having estimated m and knowing Db the increase depth of water (wd) at the bridge is assumed to be

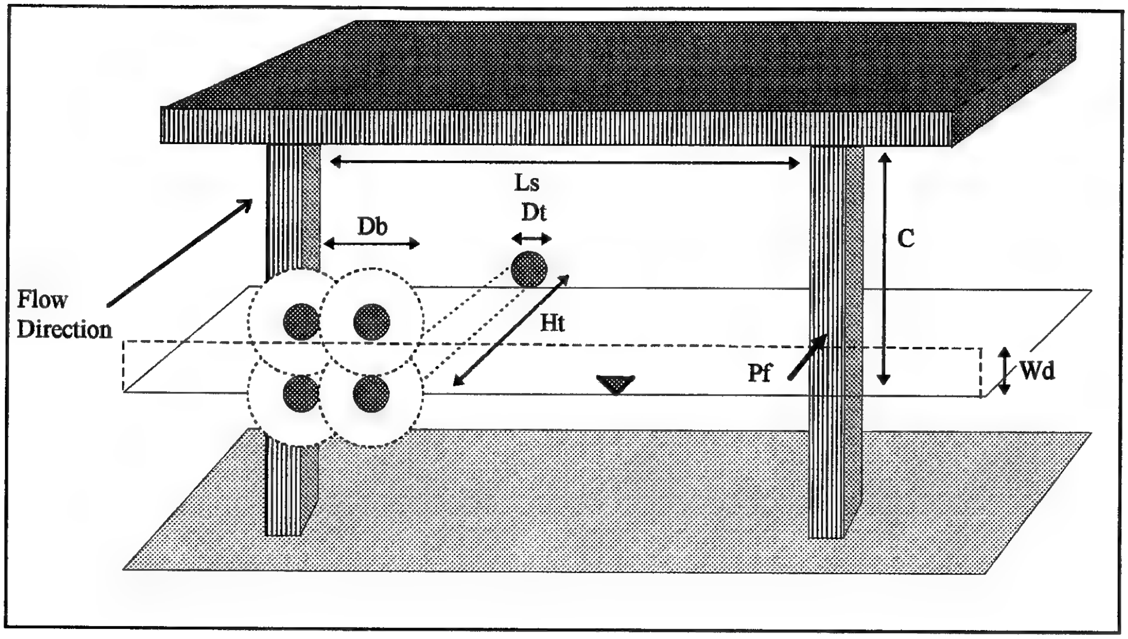
$$\Delta wd = \sqrt{mDd / 2} \quad (1.26)$$

The blockage generates a pressure force (Pf) which acts normal to the bridge is

$$Pf = \tfrac{1}{2}\gamma . mDb^2 / 4 \quad (1.27)$$

γ is the specific weight of water.

Figure 1.5 Schematic diagram of debris accumulation at bridge piers



1.5.2 Reported Instances of Debris Related Bridge Failure

A study by A. Parola, T. Fenske & D. Hagerty was initiated to investigated the basin-wide impact of the 1993 Mississippi River Basin flooding on damage to the highway infrastructure. Structural geometry information as well as hydraulic information was collected at two sites where bridges collapsed at least partly as a result of debris loading, and was noted to be a contributing factor in the lateral load and scour of many bridges. Plate 1 shows the Missouri 113 bridge over Florida Creek where floating debris was a key factor in its collapse.

Plate 1 Bridge 113 over Florida Creek Missouri. Failure due to debris loading.

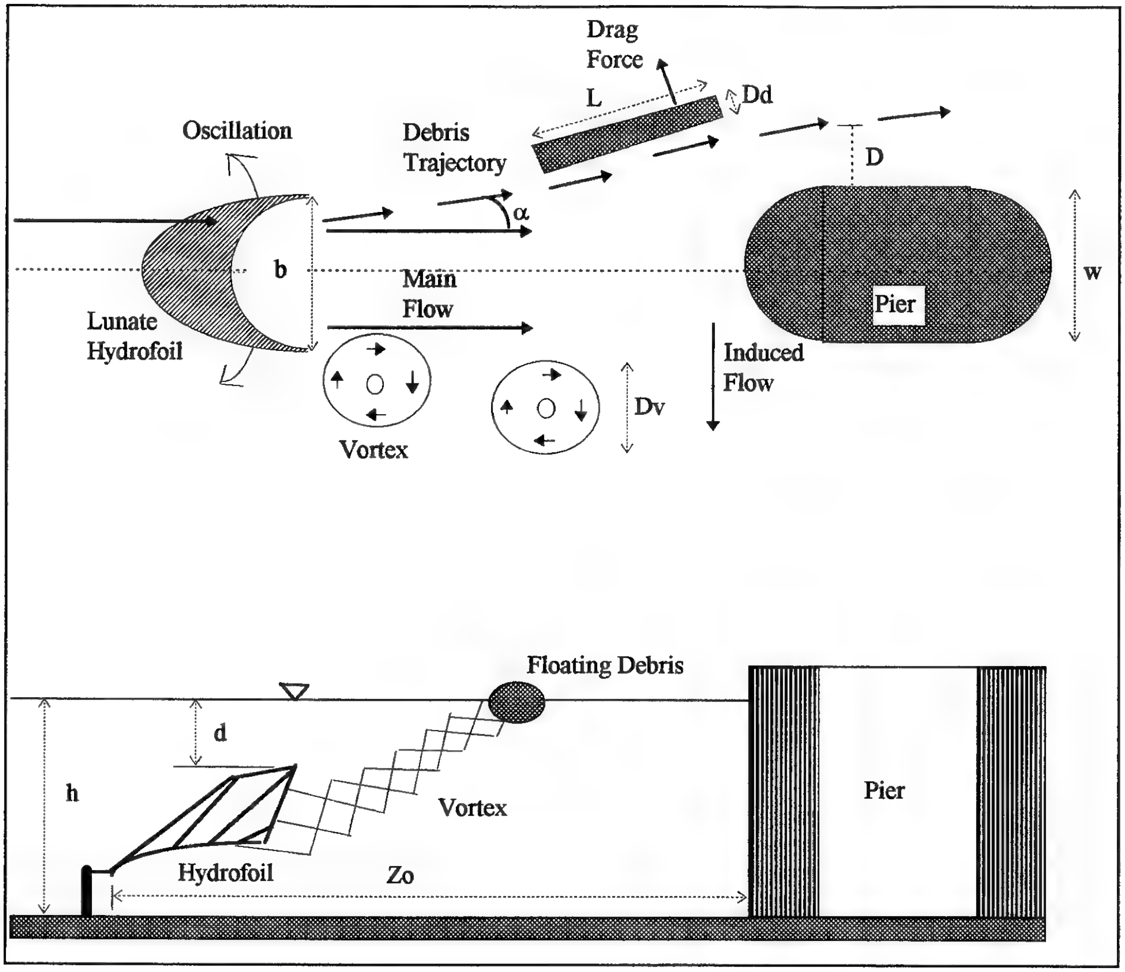
1.5.3 Methods for Managing Floating Debris at Bridges

Only one paper has been found that directly addresses debris management at bridges. S. Saunders & L. Oppenheimer (1993) believe that conventional methods of protecting piers from floating debris are inadequate. They comment that the use of pilings or some other barrier upstream of a bridge can actually exacerbate the problem because the debris accumulated may be released at once as a raft which cannot be pass under the bridge. They describe a novel deflector, a lunate shaped hydrofoil which generates counter-rotating streamwise vortices in its wake positioned below the surface so that it is not impacted by debris upstream of the piers so that the vortices migrate to the surface ahead of the pier. The idea being that the near surface flow induced by the vortices deflects the debris safely around the pier. Figure 1.6 shows the hydrofoil in elevation and planform. The foil is mounted on a tether or pylon at a depth, d, below the surface and a distance, Zo, upstream of the pier and is inclined at an angle such that the force on the foil is downwards and the reaction on the water causes a local motion upwards towards the surface. After interacting with the vortex debris is deflected at the angle,α, and is displaced sideways by a distance, D, by the time it reaches the pier. A flume model constructed by Saunders & Oppenheimer indicated that the vorticity

remains highly concentrated for a distance of about 20 times the span of the hydrofoil, b, when b=0.6xh (depth of flow). The problem is characterised by a bridge pier width w and by the size of the debris. An average debris size is utilised with diameter Dd and length L. The vortex produced by the device has a characteristic diameter, Dv, of order b (hydrofoil span). If Dd > Dv then the vortex will not impart a net motion to the debris, so they recommend a value of b > 2Dd or b = w (pier width) as, they assume, the majority of debris will have a diameter less than the pier width and this scaling will insure that the vortex is positioned correctly with respect to the pier. It is also suggested that the device be tethered so that it can oscillate transversely to the flow, so that the vortices will tend to destabilise any debris that might have accumulated on the face of the pier.

In flume tests the hydrofoil is reported to work very effectively and the device would appear to offer a promising approach to managing floating debris at bridges. However, if the average debris length is greater than the pier spacing debris floating with their long axis transverse to the flow are still likely to be trapped and the vortices might even turn flow parallel debris through 90 degrees so they become jammed between adjacent pier faces.

Figure 1.6 Hydrofoil debris deflector



1.6 DEBRIS CONTROL AT LOCKS, DAMS AND WEIRS

1.6.1 Introduction

Floating debris can create severe problems for a variety of structures and water based activities. Debris can destroy the propellers of recreational and commercial boats and cause damage to boat hulls. Navigation lock operation can be impaired by debris caught on a gate sill. Floating debris has the greatest economic effect on users of large quantities of water such as hydro-electric and thermal electric generating plants and municipal water systems. On occasion dam gates can become stuck partly open by debris intrusion and severe downstream bed scour may occur. Users must therefore install devices to prevent floating debris from entering and damaging their turbines, valves, gates, and pumps. Theses devices do however cause a slight reduction in intake capacity and are themselves susceptible to impact damage from large debris. Floating debris can also damage the upstream slopes of dams through wave action which hammers debris against the dam wall and other structures.

The following review of floating debris problems and control systems is largely taken from two REMRR (Repair, Evaluation, Maintenance and Rehabilitation Research Program) reports by R. E. Perham, Elements of floating debris control systems (1988), and Floating debris control ; a literature review (1987) .

Floating debris enters water courses through the following mechanisms.

a) Wind and wave action

On lakes and large rivers waves erode the shoreline causing tree topple into the water. Structures such as docks can be smashed by waves, and much of the flotsam can remain in the water. Wind and wave action can also cause the removal of debris from natural storage areas such as bays and coves. Wind throw is a major source of

debris input in streams in forested areas and wind has also been known to carry appreciable quantities of sagebrush and tumbleweed into rivers in the western USA

b) Ice Break-up

Moving ice in the spring break-up can increase the undercutting of riverbanks, and trees can be damaged and broken by the force of moving ice.

c) Forest Litter

A larger litter input is derived from leaves from deciduous trees and some conifers. Forest litter is usually protected by the tree canopy during summer and by a snow layer in the winter, however in early spring trees are without leaves and heavy rains will wash the litter away.

e) Forestry Practices

Forest lands soak up large quantities of water and reduce floods and erosion that bring floating debris to the streams and rivers. If a generous ground cover is maintained during tree harvest and roads are made erosion resistant, forest land can still protect the watershed. The harvest of trees on a reasonable schedule will reduce the number of dead trees that may fall into the streams and rivers.

f) Debris Jams

Debris jams may be moved en-mass by a large flood flow or they may be broken down over a long period of time by natural effects such as decomposition.

g) Beaver Dams

The quantity of debris brought into streams by beavers is unknown, but may be a substantial proportion of the total load in some watersheds.

h) Man-made Materials

This includes decaying wooden structures such as piers and wharves, and organic and synthetic material from dumps improperly located along water bodies, and general littering.

1.6.2 Collecting Floating Debris

A) Natural Features

Key debris create jams which are natural stores of large quantities of potential floating debris. Debris also accumulates in small bays and sloughs when water currents and winds are directed favourably.

B) Fixed Structures

Baffle Walls: This is a vertical wall placed in front of an intake structure to intercept debris and thereby reduce impact loads on the intake debris rack. The wall extends several feet below the water surface. Trash rack cleaning and removal is done in a space between the baffle wall and the intake structure.

Dikes : Vane dikes can be used to guide debris into a holding boom or other collection structure, and are place, for example at China Bend on the Columbia River, on the outside of bends where debris has a natural tendency to move to.

Trash Struts : Trash struts are beams placed in front of an intake in an open framework so that large debris, such as whole trees, will not enter water conduits.

Trash Racks : These are probably the single most important debris control device. The rack is faced is faced with a series of vertical parallel bars to facilitate cleaning. The rack face usually has a slope to facilitate raking.

C) Moveable Structures

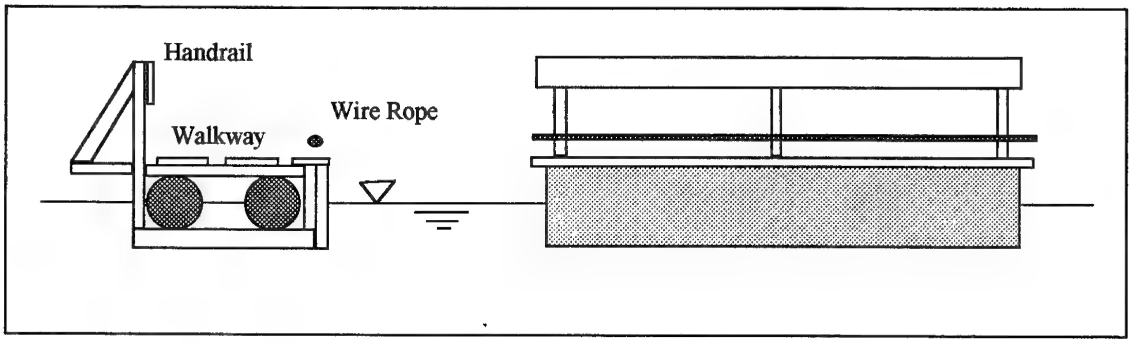
Booms : Booms are a chain of logs, drums, or pontoons secured end to end, floating on a reservoir so as to divert debris. Figure 1.7 shows an example of a log boom

Retention Boom : These are located and sized to hold debris inside or outside an area.

Deflector Boom : The deflector boom is a line of floating elements set at a steep angle to the river currents. Debris is moved along the smooth face of the boom by the hydraulic drag of the current. Debris is then moved laterally to a holding pond where it is eventually removed. They are also used to route debris around structures such as docks, and to keep it away from intakes.

Nets : Nets are used to collect and hold debris.

Figure 1.7 Double Log Log Boom



1.6.3 Removing Floating Debris

Floating debris is removed from water bodies by a variety of machines and manually operated tools, which often takes the form of existing equipment which has been modified in some manner so that it can handle debris better. For example, the welding of teeth onto a clamshell bucket to give a better grasp of debris.

In addition to equipment modifications, techniques have been developed that make the removal process more efficient or less troublesome. For example, when a trash rack is being raked, the flow through the unit that it protects is reduced or completely stopped. Debris is then easier to remove from the bars. Many techniques have been developed for site specific reasons, such as the continuous removal of debris as it is carried to a dam by high spring flows because when flow slackens the prevailing wind can blow the debris all over the pool.

The following is a list of the most common equipment used for floating debris removal.

a) Trash Rakes :

Hand Rakes : This is an implement with projecting tongs used to remove small debris from trash racks of small hydroelectric plants and other small water intakes. The rake itself is a good tool, but the process is labour intensive.

Shoreline Rakes : Floating debris stranded along the shoreline may be collected with some efficiency with a special rake on a crane-operated dragline. The debris is collected from around the anchor site into one spot and a set of log tongs or a clamshell is used to lift the debris into a container.

Self-powered Trash Rake : A variety of self-powered trash rakes are used to clean debris from trash racks. In a typical system a gantry crane is driven to a specific trash rack, the rake lowered by drum hoist down through the debris accumulation and the a raking bottom shelf opened automatically. At the bottom of the trash rack the raking shelf rotates back to the horizontal raking position and its individual fingers reach between the trash rack bars. The rake, raised by cable along up the face of the rack scrapes off the accumulated debris and at the gantry the debris is dumped into a hopper car or sluiceway.

Gantry crane-operated trash rakes : Hydroelectric plants have an intake gantry crane that moves along rails on the forebay deck from one end of the plant to the other. It can support many essential functions including trash raking.

b) Cranes and Hoists : a wide variety of cranes and hoists, in conjunction with buckets, tongs and grapples can be used to remove debris from the face of dam walls.

c) Loaders : In the situation where floating debris is deflected by booms into holding areas that can be drained, debris can be loaded into trucks using crawler or wheel type loaders.

d) Conveyors : There are several types of conveyor that can be used to lift material from the water to a disposal unit. An appropriate conveyor is the flight conveyor which has scrapers mounted at intervals, perpendicular to the direction of travel, on endless power-driver chains operating within a trough. The main problem with a conveyor is feeding material into it. A variety of techniques have been used to overcome this however, including high pressure nozzles to push debris, propellers to draw water through the conveyor, and men using pike poles.

e) Boats : Multipurpose workboats can be used to tow roundup booms, shove debris along a boom or flush it away from some location with propwash. There are also a number of specially designed debris collection boats in operation in the USA for example, the USAED boat used in San Francisco Bay. This boat has twin bows with a large space in between where a chain net is positioned as a scoop. An onboard crane is used to set a full net on the deck and to replace it with an empty one.

f) Travelling Screens : A travelling screen is a flexible screen surface that moves like a conveyor belt, or it is a rotating perforated drum. The screen blocks the water intake so that water must flow through it. The screen moves slowly up into a location where the accumulated debris is removed by water jets. The device is used to

good effect in the English land drainage and pumping systems which carry a lot of grass and small debris.

g) Air Bubblers : An air bubbler is used to remove small-sized debris from vertical trash racks at the Wider Dam, on the Connecticut River, USA It consists of a horizontal brass pipe with multiple holes, anchored at the bottom of each trash rack and fed from a compressed air tank. The intake water flow is stopped prior to the air being discharged and the debris rises to the top where it passes over a submersible gate.

1.6.4 Debris Passage

Debris can become a hazard to the operation, if not the integrity, of a dam. To avoid problems of this nature at many hydrodams, the appropriate gate or gates are opened to the necessary height or depth to send the floating debris down stream.

Dam gates: Dam gates can be raised to flush debris downstream provided this action does not cause scour downstream of the dam. However, because debris floats on the surface gates, in general, must be raised a substantial distance to achieve the water velocities needed to take the debris down and through the opening.

Logways/sluiceways: Many dams in areas where logging is an important industry, such as the north-western United States and Canada, will contain logways and sluices for passing logs and pulpwood through the structure. The logway is mainly a sloping flume through which water flows to carry the logs to a point below the dam. The passage may contain a conveyor system.

1.6.5 Disposing of Debris

a) Useable Materials

Structural Materials: Some logs may be large enough for structural applications, if the logs are in good condition.

Firewood: In general, a fair portion of debris can be dried and cut up for firewood, but the extent of its usefulness depends on how clean it is.

b) Unusable Materials

Useless debris should be discarded in a locally acceptable manner.

Burning: Debris may be burnt on land or on the water. Debris can be brought ashore by workboat and bag boom or similar scheme where it is lifted out and piled on the ground to be burned. Floating debris can also be burned on water, where permitted, using a barge and an air-curtain burner. If burning is prohibited by local regulations, disposal can be accomplished by burial in suitable locations near the collection sites. Debris should never be placed in areas where it may be carried away by stream flow or where it blocks drainage of an area.

1.6.6 Summary

Floating debris build-up is a continual problem at locks, dams, bridges and water intakes and even causes disruption of water based recreation activities. As a consequence debris control systems have been developed, which are often site specific, that incorporate various collection, removal and disposal elements. These systems are, inevitably, costly to implement.

However, in order to develop a cost effective debris control system at a new structure it would be beneficial to have some understanding of the debris dynamics within the relevant catchment area, upstream of that structure. For example McFadden and Stallion (1976) undertook a study for the Alaska District Corps of Engineers, to determine

the amount, source, and content of debris on the river, and the magnitude of water levels which could cause a substantial debris movement. Also, of particular interest were the average size of the debris pieces and their potential for jamming or damaging the outlet structure of the Chena River Flood Control Dam which was being constructed at the time. Their basin-wide studies helped them make more informed recommendations for counteracting log jamming in the dam gates. A system of debris-aligning pilings was advised with the spacing based upon maximum debris dimensions encountered on the river, and a back-up hoist with clam-shell bucket to remove logs that might manoeuvre into a jamming position. A cable boom system was rejected on the grounds that it was not as easy to clean as the gates themselves and presented a hazard to navigation.

1.7 MANAGEMENT STRATEGIES

A comprehensive study of coarse woody debris in relation to river channel management has been carried out by Gregory & Davis (1992). They collated the findings of 22 papers, many of which have been cited above, and produced a preliminary list of management criteria with regard to debris jams. Appendix B shows Gregory & Davis' table of literature and the authors' findings which form the basis for the treatment of management options here.

Prior to 1970 there was a general consensus that all debris should be cleared form channels, but after that date it was acknowledged that there were advantages to be gained by maintaining debris accumulations.

Arguments for debris removal include :

a) To improve navigation

b) To increase channel conveyance by reducing roughness

c) To eliminate bank erosion

d) To facilitate the migration of fish, especially salmon (after MacDonald, 1982).

Evidence that debris should remain in place is quite convincing, however, and, for example, Gregory & Davis' study (1992) in the New Forest (U.K.) led them to the conclusion that debris removal was, on the whole, undesirable. (Figure 1.8.). It should be noted, however, that this study, as with most others cited, was carried out in an essentially stable, equilibrium channel environment, where changes to channel morphology are negligible and significant impacts relate mostly to ecological habitat diversity.

The effective debris management strategy depends on the underlying aim in terms of:

a) improving drainage

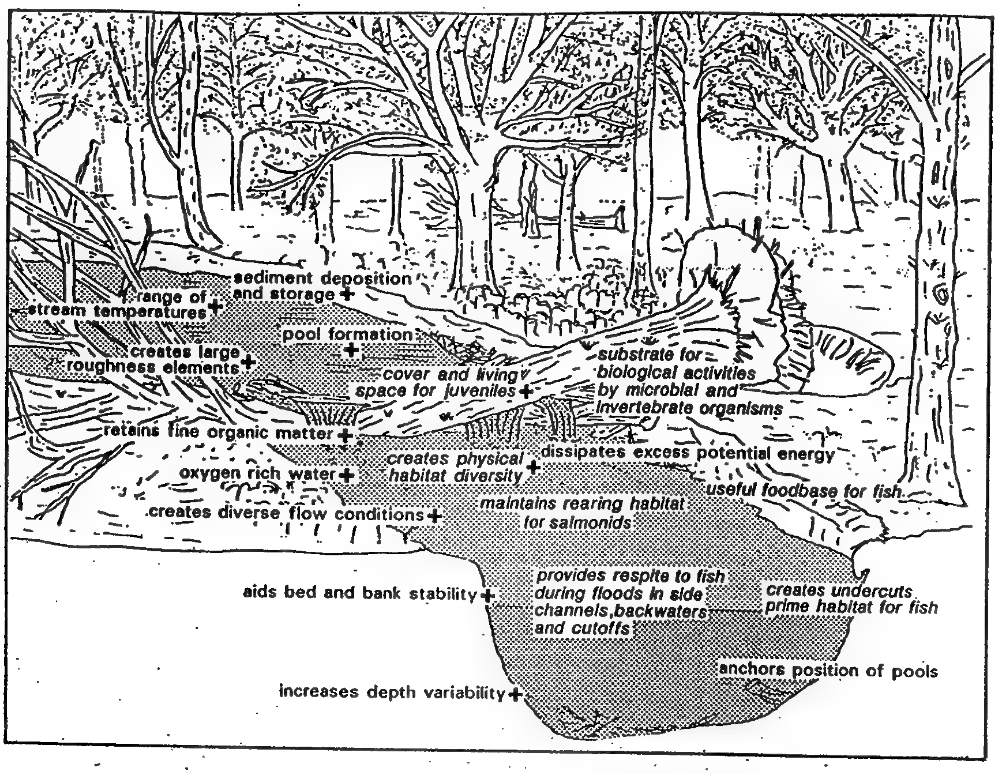
b) flood mitigation

c) navigation

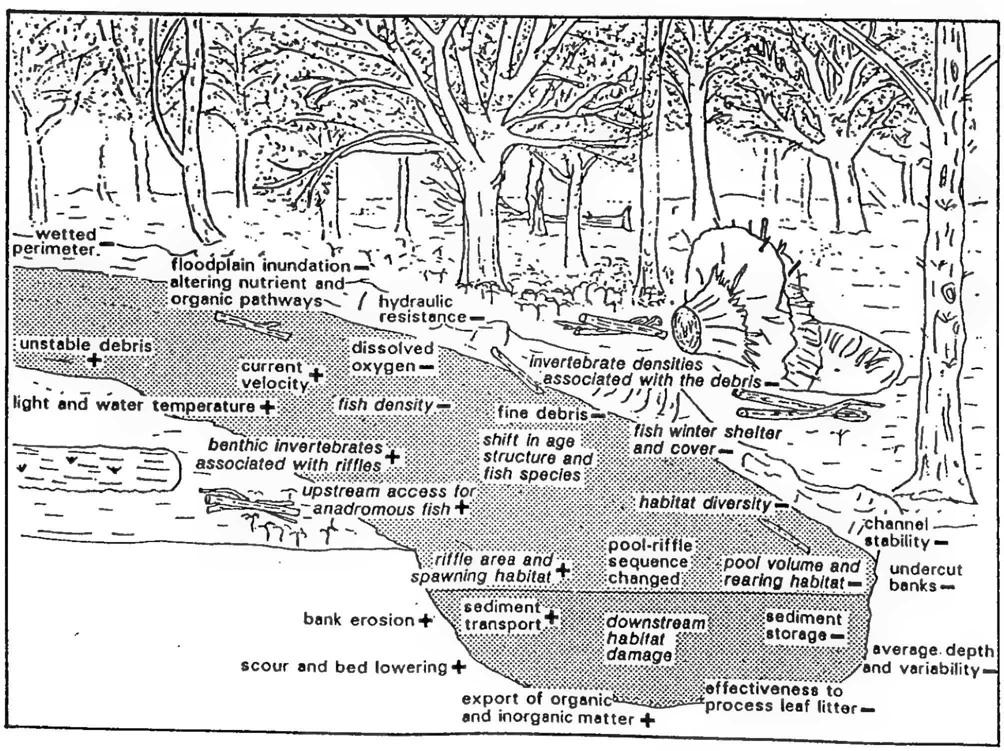
d) enhanced fish migration, or

The Significance of Coarse Woody Debris Dams for Channel Morphology, Channel Proccesses & Ecology **Figure 1.8**

DAM PRESENT



DAM REMOVED



Characteristics which relate to ecological habitats are shown in italics

Reproduced by permission of John Wiley & Sons Ltd., after Gregory & Davis, 1992

e) improved aesthetic qualities.

Gregory & Davis cite three aspects of hydrogeomorphology (after Coburn, 1989) relevant to an analysis of channel management:

1) It is necessary to know the relationship between river channel processes and river channel morphology

2) It is necessary to be aware of the timescales over which river channels may adjust

3) It is necessary to consider channel management in the context of river basin management

More specifically, debris management must consider :

1) Channel stream power characteristics

2) Sediment movement and storage relationships (high/low; fine/coarse sediment; suspended/bedload).

3) Channel stability

4) Size and character of river channel in relation to debris size

5) Spacing and frequency of jams

6) Size and character of jam, and orientation of component material

7) Age and stability of component material.

The management recommendations for woodland areas suggested by Gregory & Davis, are shown in Figure 1.4. They conclude that "... a conservative approach to debris removal should be adopted for most areas, but that different strategies are needed according to the characteristics of particular localities". This statement is all-encompassing but there is no consensus as to the nature of these "different strategies". For example, Gregory & Davis (1992) suggest that, based upon their literature survey, in channels with low stability, no debris should be removed (see figure 1.9). However, this is in direct contradiction to practice in the U.S.A, described by Brookes

(1985, pg. 64). "In North America the concept of channel restoration was developed in North Carolina under the funding of the Water Resources Research Institute of the State University ...Restoration is achieved by removing debris jams and providing uniform channel cross-sections and gradients whilst preserving meanders, leaving as many trees as possible along the stream banks, and stabilizing banks with vegetation and rip-rap where necessary ...".

A similar type of approach, known as stream renovation, has been advocated based on experience on the Wolf River, Tennessee (Mc Connell et al., 1980).

The recommendations of George Palmiter (Institute of Environmental Sciences, 1982) are similar and include the following steps :

a) Removal of log-jam material by cutting it to a manageable size

b) Protection of eroding banks using brush piles and log-jam material, with rope and wire

c) Removal of sand and gravel using brush-pile deflectors

d) Revegetation to stabilize banks and shade-out aquatic plants

e) Removal of potential obstructions such as trees and branches

In the light of the literature and these recommendations it was decided to analyze the debris jam/channel morphology relationships with the aim of determining suitable management criteria, because current recommendations and maintenance practices appear to be contradictory.

DETERMINANTS FOR A MANAGEMENT STRATEGY FOR RIVERS IN WOODLAND AREAS	Figure 1.9

	CHANNEL VARIABLE	MANAGEMENT STRATEGY: CHANNEL CLEARANCE	PARTIAL DEBRIS CLEARANCE	NO REMOVAL	LIMITED DEBRIS CLEARANCE
CHANNEL ENVIRONMENT	Stream Power		←	high	→
		←	low	—	→
	Sediment Storage and Tansport		←	high	→
		←	low	—	→
	Channel Width / Tree Height	←	high > 1	→	
			←	low < 1	→
	Channel Stability	←	high	—	→
				← low	→
	Adjacent Landuse Value	← high value agricultural →	← grazing →	← managed / old growth forest	→
DEBRIS ENVIRONMENT	Spacing and Frequency of Dams	← excessive →	← high →	← natural levels →	← low > 5 - 10 channel widths →
	Debris Budget Loading	← excessive →	← high →	← natural levels →	← low →
	Size and Character of Coarse Debris	←	< 10 cm diameter	→	
			←	> 10 cm diameter	→
		←	green foliage →		
	Size of Blockage	> 10 channel widths long, debris jam	> 5 channel widths long	active debris dam	partial debris dam
	Anchorage of Debris	← no anchorage →	← single end anchorage →	← both ends anchored	→
	Stability of Debris	← low →	← moderate →	← high	→
	Orientation of Debris to Flow	← 60-90 degrees	→ ←	parallel to flow	→
	Residence Time of Logging Debris	← 24 hrs	→ ←	> 5 yrs since introduction	→
IMPACTS	Habitat Diversity	← low	→ ←	high →	← needs enhancing →
	Aesthetics	← low importance	→ ←	high importance	→
	Blockage to Fish Migration	← possible	→ ←	negligable	→

(modified from Gregory & Davis, 1992)

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APPENDIX A
LITERATURE REVIEW BY GREGORY & DAVIS

Table 1

AUTHOR	SIGNIFICANCE																							PERMANENCE OF DAMS	BUDGET
	MORPHOLOGY									PROCESS										ECOLOGY					
	general	width/channel widening	pools and riffles	plunge pools	bank stability	resistance/channel roughness	channel pattern	cutoffs	long profile/stepped profile	general	flow pulses	sediment transport	sediment storage	erosion distribution	potential energy dissipation	organic matter storage	organic carbon storage	sediment/channel bars	flood peak travel times		fish populations	fish/aquatic habitats			
BILBY & LIKENS 1980																	■							-	- Percent of standing organic stock contained with dams 20-75% - average dam spacing 3-50m - 40% of carbon input in form of leaf litter
GREGORY & GURNELL 1988	■									■														100-200 years	-
GREGORY, GURNELL & HILL 1985																			■					- in less than 12 months 36% changed position or were destroyed - 36% changed character	- average dam spacing 27m
HARMON et al 1986	■												■			■					■			Factors affecting movement	- Input of debris rates of decomposition - types of decomposition - amount of distribution of debris - Factors controlling decomposition decay models
HEEDE 1981												■	■		■									-	- Average spacing of dams 2.8-15.2m
HICKIN 1984						■	■																	-	-
HOGAN 1987	■	■	■	■	■				■				■											40-90 years remove for unlogged channels.	- input, output & storage components in logged, unlogged & torrented catchments. - LOD orientation - LOD frequency distribution.
KELLER & TALLY 1979	■	■	■						■	■			■								■			Can be greater than 200 years	- debris loading 19.6-84.8 kg/m^2 - methods of input & output - inverse relationship system between debris loading & stream size
KELLER & SWANSON 1979	■	■		■	■			■	■				■		■									May reside in streams for more than a century	- model of processes affecting debris input - inverse relationship between debris loading and stream size
LIENKAEMPER & SWANSON 1987																								- less than 10% movement in 8 years. - 65% redistribution in 6 years. Turnover time 12-83 years	- debris loading 230-750 $Mg\ Ha^{-1}$. - source and methods - inverse relationship between debris loading and stream size.
LIKENS & BILBY 1982	■											■												-	-
MACDONALD, KELLER & TALLY 1982	■		■		■				■			■	■											- residence time can be for several centuries. - movement primarily by flotation at high flows	- inverse relationship between debris loading and stream size
MARSTON 1982													■		■						■			-	-
MOSLEY 1981	■		■									■		■										-	-
PEARCE & WATSON 1983									■				■											-	-
ROBINSON & BESCHTA 1990	■	■	■																		■			-	- debris loading generally increased with stream size
SEDELL et al 1988			■																		■	■		- residence time varies with the age and species of the stand - decay rate 1% per year.	- mechanism or input - processes of removal damage - decay rate - debris loading
SPENCER, DOUGLAS, GREER & SINUN 1990		■											■		■	■		■						- minimum residence time possibly related to the mean annual flood recurrence interval.	- short term debris build up followed by subsequent removal by a high density low return period storm. - number of organic steps related to antecedent hydrometeorological events. - number of dams reduced from 1.3 per 100m in March 1988 to 0.5 per 100m in April 1988.
SWANSON, LIENKAMPER & SEDELL 1976		■																						- residence time can be greater than 100 years	- debris torrents are the only method of moving very large debris.
SWANSON et al 1984																						■		-	- debris loading average 9.4kgm^{-2} coarse debris 0.9kgm^{-2} fine debris
SWANSON & LIENKAEMPER 1978	■											■										■		- residence time can be greater than 100 years. - methods of debris movement	- mechanisms of input - debris movement
ZIMMERMAN et al 1967		■																						-	-

APPENDIX B

Large Woody Debris Formation Survey used by Smith And Shields (1992)

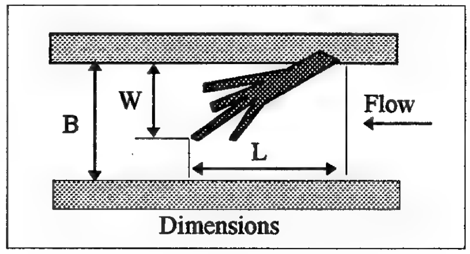
Stream Name ______________________

Reach Information ______________________

____

____

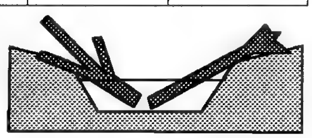
Date ______________ Time ______________



Width-Perpendicular to Flow Direction

	W<B/4	B/4<W<B/2	B/2<W<B
L<B/2			
B/2<L<B			
L>B			

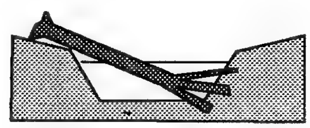
Length-Parallel to Flow Direction



TYPE A : COLLAPSED BRIDGE

Width-Perpendicular to Flow Direction

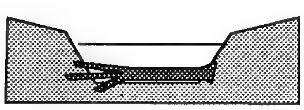
W<B/4	B/4<W<B/2	B/2<W<B



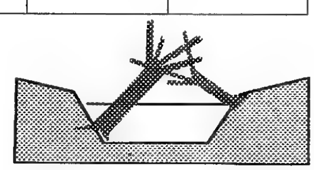
TYPE B : RAMP

L<B/2			
B/2<L<B			
L>B			

Length-Parallel to Flow Direction



TYPE C : DRIFT



TYPE D : STREAMBANK TREES

APPENDIX C

Method for predicting afflux due to LWD, developed by Gippel et. al. (1992)

The recommended procedure for predicting the hydraulic effect of managing large woody debris from a lowland river is as follows:

1) Measure the LWD:

- projected length of LWD (L_*)
- mean diameter of LWD in flow (d)
- angle of orientation of the LWD in the flow (α)

2) Measure the channel morphology:

- cross-sectional area of flow at selected discharge (A)

3) Measure or estimate flow characteristics at selected discharge:

- depth of flow downstream of LWD (h_3)
- velocity downstream of LWD (U_3)

4) Select a drag coefficient:

- based on angle of orientation and snag form (C'_D) using Figure 1.10 or 1.11

Figure 1.10 : Variation in drag coefficient with angle of rotation to the flow, measured for a model LWD complete with trunk, branches and butt, and for other combinations of these components

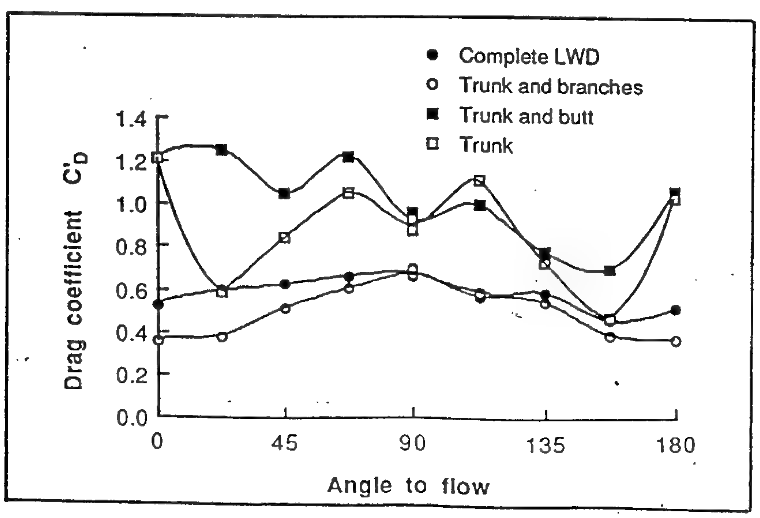
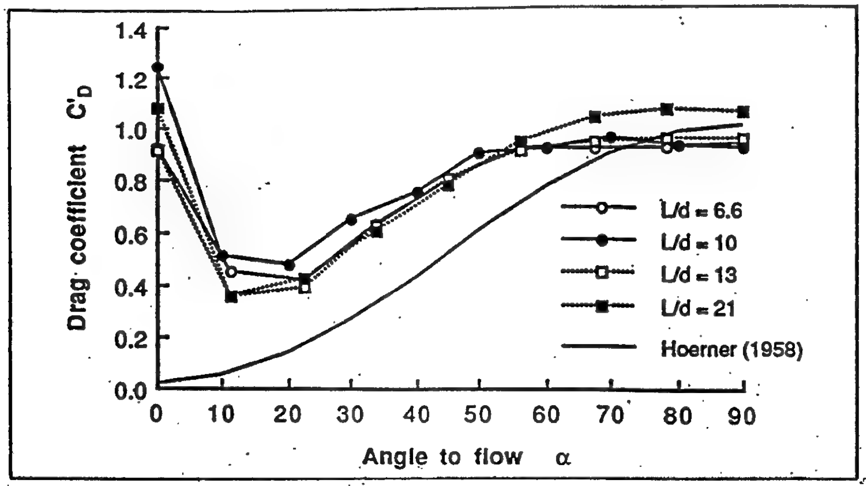


Figure 5.2 : Variation in drag coefficient with angle of rotation for cylinders of various lengths and diameters. Hoerner's (1958) relationship is for infinitely long cylinders.



5) Calculate the following:

- Froude number downstream of LWD

$$F = \frac{U_3}{\sqrt{gh_3}}$$

- blockage ratio of LWD

$$B = L_* d / A$$

- drag coefficient corrected for blockage

$$C_D = C'_D(1-B)^{-3}$$

6) Calculate afflux due to LWD:

$$\Delta h = \frac{h_3\left[\left(F^2-1\right)+\sqrt{\left(F^2-1\right)^2+3C_D BF^2}\right]}{3}$$

7) Calculate the upstream extent of the afflux using a backwater procedure

8) Repeat the calculations for various management strategies such as lopping and rotation.

APPENDIX D

DEBRIS JAM FIELD RECCONAISANCE FORM

Site Location ______________________ **Site No.** ________________
Map Reference ________________ **Date** ____________________
Special Features ______________ **State of Flow** __________________

Field Sketch

JAM CHARACTERISTICS

Barrier to flow and sediment routing (1)		max height of jam	% of channel cross-section blocked by jam (2)	Jam Flow Direction		zones occupied by jam (3)	%
Active				Dam		1	
Complete				Deflector		2	
Partial				Underflow		3	
				Flow Parallel		4	

Alpha angle of key debris ____________________ (4)

Beta angle of key debris ____________________ (5)

Channel Planform ______________________ **Knickpoints/zones** ______________

Sedimentation	Location in channel	Estimated area / depth
Backwater Sediment Wedge		
Bar		

Erosion	Location in channel	Estimated area / depth
Bed scour		
Bank erosion		

Bank Erosion Severity	1	2	3	4
Left				
Right				

Sediment Type	Gravel	Sand	Silt	Clay
Estimate D50				

Vegetation Characteristics	Type / Species	Estimated age	Position on bank/in channel	Estimated height/diameter
Debris Jam				
Riparian				

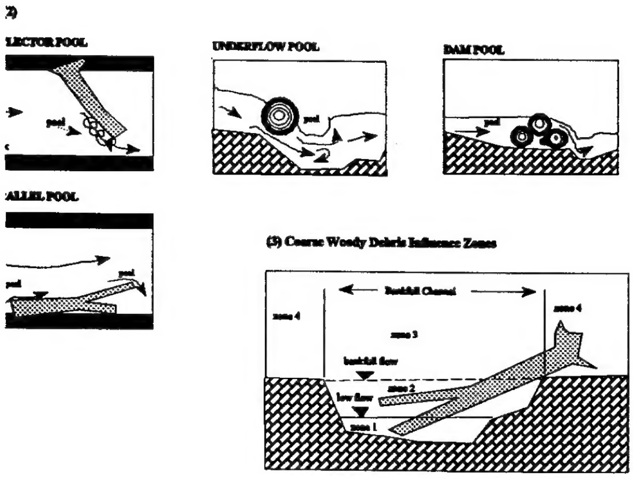
Notes

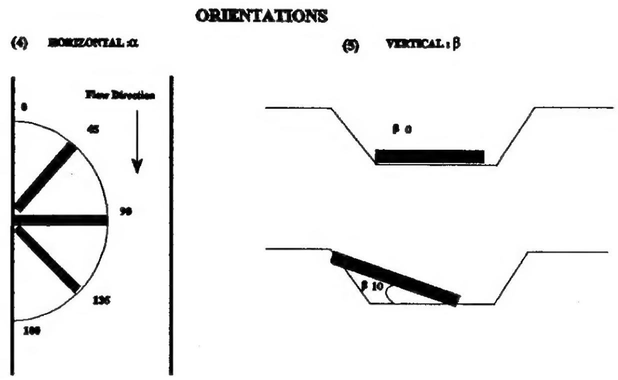
(1)

Active: jam forms a complete barrier to water and sediment movement and also creates a distinct step, or fall in the channel profile

Complete : complete barrier to water/sediment movement, but no significant step

Partial : jam is only a partial barrier to flow





Bank Erosion Severity

None :very stable, no evidence of signficant erosion
Slight : small area of bank failure, not continuous or widespread
Moderate : significant portion of the banks are eroding, however, rate does not appear excessive
Severe : banks are continuously eroding along the length of the site